Chapter 1 - Introduction to the Framework

California is a world leader in science and technology, and as a result, enjoys both economic and intellectual prosperity. Our history as a nation and as a state is rich in innovation and invention. Educators have the opportunity to foster and inspire in students an interest in science, with the goal of having students gain the knowledge and skills necessary for California's work force to be competitive in the global, information-based economy of the 21st century.

The Science Framework for California Public Schools is the blueprint for reform of science curriculum, instruction, professional preparation and development, and instructional materials in this state. It outlines the implementation of the *Science Content Standards for California Public Schools* (adopted by the State Board of Education in 1998) and connects the learning of science with the fundamental skills of reading, writing, and mathematics. The Science Content Standards are a concise description of what to teach at specific grade levels, and this framework extends those guidelines by providing the scientific background and the classroom context.

Glenn T. Seaborg, one of the great scientific minds of our time, wrote in his essay *A Letter to a Young Scientist* :

> *Science is an organized body of knowledge and a method of proceeding to an extension of this knowledge by hypothesis and experiment.*[1]

This Framework is intended to organize the body of knowledge that students need to learn during their elementary and secondary education, and to illuminate the methods of science that will be used to extend that knowledge during the students' lifetimes.

While the world will certainly change in the new century, and in ways that we can scarcely begin to predict, California's students will be prepared to meet new challenges if they have received a sound, basic education. This framework outlines the foundation of science content knowledge students need to have, and the analytical skills that will enable them to advance that knowledge and absorb new discoveries.

Audiences for the Framework

The primary audiences for this framework are the teachers and other educators who are responsible for implementing the *Science Content Standards*. These include elementary and middle school teachers with multiple subject credentials, middle and high school teachers with single subject credentials in science, and those who may be teaching outside of their primary area of expertise. The framework is designed to provide valuable insights to both novice and expert science teachers.

Designers of science instructional materials will use this framework as a guide to the *Science Content Standards*, and as an example of the scholarly treatment of science that is expected to show in their work. Publishers submitting materials for adoption in the State of California are held to a set of rigorous criteria described in this framework. These include careful alignment with and comprehensive coverage of the *Science Content Standards*, good

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[1] *Gifted Young in Science: Potential Through Performance.* Edited by Paul Brandwein and others. Arlington, VA.: National Science Teachers Association, 1989. The late Dr. Seaborg was Chair of the California Academic Content Standards Science Committee that created the *Science Content Standards for California Public Schools*.

program organization and provisions for assessment, universal access for students with special needs, and instructional planning and support for the teacher.

The organizers of programs of pre-service professional preparation and in-service professional development alike will find this framework helpful in their efforts. A high degree of skill is needed to teach science well, and training programs for teachers need to be especially mindful of the expectations placed on students.

Scientists and other professionals in the community often seek ways to help improve their local schools, and they will find this framework helpful in focusing their efforts on a common set of curricular goals. By providing ideas and resources to the classroom teacher that are aligned with grade-level standards, the outreach efforts and donations from these generous individuals will be put to best use.

For many high school seniors, commencement is followed shortly thereafter by baccalaureate courses. This framework communicates to the science faculty at all California institutions of higher education, what they may expect of entering students.

Finally, the parents, guardians, and other caregivers of students will find this framework useful, as they seek to help children with homework, or understand themselves what their children are learning in school.

Instructional Materials

One of the best corrective measures that local education agencies can take is to ensure that all K-8 teachers are provided with instructional materials currently adopted by the State Board of Education, particularly in science, mathematics, and reading-language arts, and are trained in their use. These materials are subjected to a rigorous process of review, and provide teachers and other instructional staff with guidance and instructional strategies for helping students having difficulty. In choosing instructional materials at the high school level, local education agencies need to be guided by the Science Content Standards and these same evaluation criteria in selecting comprehensive instructional materials for biology/life sciences, chemistry, physics, and earth sciences. An analogy used in the Reading-Language Arts Framework for California Public Schools is equally applicable to the teaching of science: Teachers should not be expected to be the composers of the music, as well as the conductors of the orchestra. In addition to solid, basic instructional materials, teachers need to be able to gain access to up-to-date resources in the school library-media center that support the teaching of standards-based science. These resources must be carefully selected to support and enhance what is provided in the basic instructional materials.

The Challenges in Science Education

Long-term planning.

Elementary school students often learn much from observing and recording the growth of plants from seeds in the classroom, but are the same students well-served if seed planting is a focus of the science curriculum in the next year, and the next, and the following one as well? The same might be asked of any instructional activity. Long-term planning of a science curriculum over a span of grades helps students learn new things and develop new skills each year. A standards-based curriculum helps students moving from district to district, as they are more likely to receive a systematic and complete education.

The *Science Content Standards for California Public Schools*, and this framework, are designed to ensure that all students have a rich experience in science in every grade, and that curriculum decisions are not made haphazardly. Curricular programs need to incorporate the content standards at their respective grade levels and be comprehensive and coherent over a span of grades.

Reforming science curriculum, instruction, and instructional materials will be a time consuming process. To achieve the reform objectives, all educational stakeholders need to adhere to the guidance provided in this framework. It may be hoped that in the near future, teachers will be able to watch students file into the classroom at the beginning of a school year, and have a much greater degree of certainty about the knowledge and skills the students already possess. Less of the valuable instructional time will be spent on review, and teachers will also have a clear idea of the content their students are expected to master at each grade level and in each branch of science.

Meeting the curricular demands from other core content areas.

The Reading-Language Arts and Mathematics Frameworks are explicit in their demands for uninterrupted instructional time in these subjects. In the early elementary grades, students need to receive at least 150 minutes of reading-language arts instruction daily, and 50-60 minutes of mathematics instruction.

At the elementary school level, the pressure to raise the academic performance of students in reading-language arts and mathematics has led some administrators to cancel or curtail science instruction. This is not necessary and reflects, in fact, a failure to serve the students. This framework helps to organize and focus elementary science instruction, bringing it to a level of efficiency that it need not be eliminated.

All teachers, and particularly those with multiple subjects to teach, need to make judicious use of their instructional time. One of the key objectives set forth in the *Mathematics Framework* applies equally well to the study of science.

> *During the great majority of allocated time, students are active participants in the instruction.*

Active means, in this case, that students are engaged in thinking about science. If an activity is paced too fast or too slow, students will not be "on task" for much of the allotted time.

When large blocks of time for science instruction are not feasible, teachers must make use of smaller blocks. For example, an elementary teacher and class could have a brief but spirited discussion on why plant seeds have different shapes, or why the moon looks different each week. For grades K-3, standards-based science content is now integrated into non-fiction material as part of the State Board of Education-adopted English language arts reading programs. In the 2002 Reading-Language Arts and English Language Development adoption, for example, publishers were given the following mandate:

> *In order to protect language arts instructional time, those K-3 content standards in history-social science and science that lend themselves to instruction during the language arts time period are addressed within the language arts materials, particularly in the selection of expository texts that are read to students, or that students read.*

There is no begrudging of the extended time needed for students to master reading, writing, and mathematics, for these are fundamental skills necessary for science. The *Reading-Language Arts Framework* states this principle clearly: *Literacy is the key to becoming an independent learner in all the other disciplines.* The *Mathematics Framework* bears a similar message: *The [mathematics] standards focus on essential content for all students and prepare students for the study of advanced mathematics, science and technical careers, and postsecondary study in all content areas.*

Even with the aforementioned curricular demands, it is imperative that the science standards be taught comprehensively during the elementary grades. This is a challenge that can be met with careful planning and implementation.

Setting clear instructional objectives.

In teaching the content of the Science Standards, local education agencies must have a clear idea of their instructional objectives. Science education is meant to teach, in part, the specific knowledge and skills that will allow students to become literate adults. As John Stuart Mill wrote in 1867:

> *It is surely no small part of education to put us in intelligent possession of the most important and most universally interesting facts of the universe, so that the world which surrounds us may not be a sealed book to us, uninteresting because unintelligible.*[2]

Science education is more than the learning of interesting facts, however. It is the building of intellectual strength in a more general sense. As Arthur Bestor wrote in 1953:

> *The scholarly and scientific disciplines won their primacy in traditional programs of education because they represent the most effective methods which men have been able to devise, through millennia of sustained effort, for liberating and organizing the powers of the human mind.*[3]

Science education in grades K-12 trains the mind and builds intellectual strength, and must not be limited to the lasting facts and skills that can be remembered into adulthood. Science must be taught at a level of rigor and depth that goes well beyond what a typical adult knows, and taught "for the sake of science" and not with any particular vocational goal in mind. The study of science disciplines the minds of students, and the benefits of this intellectual training are realized long after schooling, when the details of the science may be forgotten.

Modeling scientific attitudes

Science must be taught in a way that is both scholarly and engaging. That is, an appropriate balance must be maintained between the "fun" and "serious" sides of science. A physics teacher might have students build paper airplanes to illustrate the relationship between lift and drag in airflow, but if the activity is not deeply rooted in the content of physics, then the fun of launching paper airplanes displaces the intended lesson. The fun of science can help

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[2] Inaugural Address to the University of St. Andrew, quoted in DeBoer, George E. A History of Ideas in Science Education. Teachers College Press, 1991, New York. p. 8

[3] Bestor, Arthur E. *Educational Wastelands*. University of Illinois Press 1953. p. 18.

students remember important ideas, but it cannot substitute for effective instruction and sustained student effort.

There are certain attitudes about science and scientists that a teacher must foster in students. Scientists are deeply knowledgeable about their fields of study, but typically are willing to admit that there is a great deal they do not know. In particular, they welcome new ideas that are supported by evidence. In their research, good scientists do not attempt to prove that their own hypotheses are correct, but rather that they are incorrect.[4] Though somewhat counterintuitive, it is the surest path to finding the truth.

Classroom teachers must always provide rational explanations for phenomena, and never invoke occult or magical ones. They need to be honest about what they do not know and be enthusiastic about learning new things along with their students. They must convey to students the idea that there is much to learn, and that phenomena that are not currently understood may be understood in the future. Knowledge in science is cumulative, passed from generation to generation, and refined at every step.

Providing balanced instruction

Some of the knowledge of science is best learned by having students read about the subject, or hear it from the teacher, and other knowledge is best learned in laboratory or field studies. Direct instruction and investigative activities need to be mutually supportive and synergistic. Instructional materials need to provide teachers with a variety of options for implementation that are based upon the Science Content Standards.

For example, students might learn about Ohm's Law, one of the guiding principles of physics that states that current decreases proportionately as resistance increases in an electrical circuit, operating under a condition of constant voltage. In practice, it explains why a flashlight with corroded electrical contacts does not give a bright beam, even with fresh batteries. It is a simple relationship, expressed as $V=IR$, and embodied in the high school physics standard 5b. In a laboratory exercise, students may obtain results that seem to disprove the linear relationship, however, because the resistance of a circuit element varies with temperature. The temperature of the components gradually increases as repeated tests are performed, and the data become skewed.

In this example, it was not Ohm's Law that was wrong, but an assumption about the stability of the experimental apparatus. This can be proven by additional experimentation and provides an extraordinary opportunity for students to learn about the scientific method.

Had the students been left to uncover the relationship between current and resistance on their own, their skewed data would not have easily led them to discover Ohm's law. A sensible balance of direct instruction and investigation, and a focus on demonstration of scientific principles provides the best science lesson.

Ensuring that instructional activities are safe

Safety is always a first consideration in the design of demonstrations, hands -on activities, laboratories, and science projects, on site or away from school. Teachers need to be familiar with the Science Safety Handbook for California Public Schools (1999). It contains specific and useful information relevant to classroom teachers of science. Observing and promoting safe practices is a legal and moral obligation for administrators, teachers, parents, and students.

[4] Platt, J.R. (1964). Strong Inference. *Science*, 146, 347-353.

Safety needs to be taught. Scientists and engineers in universities and industries are required to follow strict environmental healthy and safety regulations. Knowing and following safe practices in science is part of understanding the nature of science and scientific procedures.

Matching instructional activities with standards

It is important that teachers use instructional materials that are aligned with the Science Content Standards, but how do they know when a curriculum or supplemental material is a good match? The California State Board of Education establishes content review panels to analyze science instructional materials submitted for adoption in grades K-8, and these panels consist of professional scientists and expert teachers of science. Local education agencies would be well advised to use materials that have passed this stringent test for quality and alignment. The criteria are included in the framework, and may help guide the thinking of districts and schools on the adoption of grade 9-12 materials.

In brief, teachers need to use instructional activities or readings that are grounded in the content of science, and provide clear and non-superficial lessons. The content must be scientifically accurate, and the breadth and depth of the Science Content Standards need to be addressed. Initial teaching sequences must communicate with students in the most straightforward way possible, and expanded teaching used to amplify the students' understanding.[5] The concrete examples, investigative activities, and vocabulary used in instruction needs to be unambiguous, and chosen to demonstrate the wide range of variation upon which scientific concepts can be generalized.

For example, one grade 4 science standard is: *Students know plants are the primary source of matter and energy entering most food chains.* This may be taught using numerous concrete examples of biomes. Mastery of the concept, however, requires that students understand how the concept is generalized. Having learned by explicit instruction that plants are primary producers in deserts, forests, and grasslands, the students must be able to generalize the principle accurately to include other habitats (e.g., salt marshes, lakes, and tundra). While the standard is easily amenable to laboratory and field activities, the entire lesson cannot be absorbed implicitly by observation or contact with nature.

In high school, the details of this standard are expanded to considerable depth, as students come to learn about energy, matter, photosynthesis, and the cycling of organic matter in an ecosystem. The grade 4 standard prepares students to learn more, and there are many examples in the Science Content Standards of this type of "pre-teaching." For example, having students learn in grade 3 that "*all matter is made of small particles called atoms, too small to see with the naked eye*" does not make them atomic scientists. It introduces them to a way of thinking that is reinforced in grades 5 and 8, and then taught to much greater depth in high school.

This framework is designed to ensure that instructional materials are developed to the intended depth of each standard, and the relationships among standards that grade levels and branches of science.

Science and the Environment

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[5] Engelmann, Siegfried and Douglas Carnine. *Theory of Instruction: Principles and Applications.* ADI Press, Eugene OR, 1991

Environmental concerns that once received relatively little attention (e.g., invasive species of plants and animals, habitat fragmentation, and the loss of biodiversity) have suddenly become statewide priorities. Entire fields of scientific inquiry (e.g., conservation biology, landscape ecology, and ethnoecology) have arisen to address these concerns. Overall, there is an increased sense of the complexity and interconnectedness of environmental issues. The public response to California's environmental challenges has been profound as evidenced by the passage of Senate Bill 373 (Chapter 926, Statutes of 2001). SB 373 specifically requires the inclusion of the following topics in this framework:

- Integrated waste management.
- Energy conservation.
- Water conservation and pollution prevention.
- Air resources.
- Integrated pest management.
- Toxic materials.
- Wildlife conservation and forestry.

A number of the *Science Content Standards* speak to these topics directly, provide students the foundational skills and knowledge to understand them, or incorporate the concepts, principles, and theories of science that are integral to them. As appropriate within this framework, suggestions have been included of ways to highlight these topics in science instruction.

- Students in grades K-5 learn about the characteristics of their environment through their studies of earth, life, and physical sciences. For example, at grade three, students learn about how environmental changes affect living organisms.
- Students in grades 6-8 focus on earth, life, and physical science, respectively, and the study of ecology and the environment is included in each grade.
- Students in grades 9-12 expand their knowledge of habitats, biodiversity, and ecosystems associated with the biology/life science content standards. High school earth science standards include the study of energy and its usage, as well as topics related to water resources and the geology of California.

The Legislature has declared that "[we have] a moral obligation to understand the world in which [we live] and to protect, enhance, and make the highest use of the land and resources [we hold] in trust for future generations, and the dignity and worth of the individual requires a quality environment in which [we] can develop the full potentials of [our] spirit and intellect." (*Education Code* Section 8704.) Toward that end, local education agencies and individual schools throughout California are contributing to the betterment of the environment in many ways, including replacing asphalt school grounds with gardens, recycling school waste, contributing scientific data to international Web sites, and restoring local habitats.
Specific programs of environmental education enhance the learning of science at all grade levels. These programs enhance scientific and critical thinking skills, enabling students to perceive patterns and processes of nature, to research environmental issues, and to propose reasoned

solutions. Environmental education is not advocacy for particular opinions or interests, but a means of fostering a comprehensive and critical approach to issues, providing a personal sense of responsibility among students for the environment, and tying schools more closely to the life of the communities they serve.

Guiding Principles of Effective Science Programs

The following principles direct the purpose, design, delivery, and evaluation of science instruction in an effective science education program. They address the complexity of the science content, and the methods by which science content is best taught. They clearly define what a science curriculum might look like at the elementary, middle, and high school levels.

Effective science programs:

- ***Are standards-based and utilize standards-based instructional materials.***

Comprehensive, standards-based programs are those in which curriculum, instruction, and assessments are aligned with the *Science Content Standards* at all grade levels (K-8) and in content strands (9-12). Students have opportunities to learn foundational skills and knowledge in the elementary and middle grades and to understand concepts, principles, and theories at the high school level. Students use instructional materials that are adopted by the State Board of Education in grades K-8. For grades 9-12, students use instructional materials that are determined by local school boards of education to be consistent with the Science Content Standards and this framework.

A California Standards Test in science is now to be administered at grade 5, reflecting the science content standards for grades 4 and 5 (cumulative). Therefore, it is imperative that science instruction be based on complete programs that cover all the standards at every grade level. The Criteria for Evaluating K-8 Science Instructional Materials (see Chapter 7) specify that adopted materials provide "all content Standards as specified at each grade level are supported by topics or concepts, lessons, activities, investigations, examples, and/or illustrations, etc., as appropriate."

At the high school level, the science content standards do not prescribe a single high school curriculum. To allow local education agencies and teachers flexibility, the standards for grades 9-12 are organized as content strands, and there is no mandate that a particular content strand be completed in a particular grade. Students enrolled in science courses are expected to master the standards that apply to the curricula they are studying, regardless of the sequence of the content. Students in grades 9-12 use instructional materials that are consistent with the science content standards and this framework, and local education agencies must critically review the standards maps that are now to be provided by publishers of high school instructional materials.

The California Standards Tests for grades 9-11 are content specific depending upon the science courses in which they are enrolled. Blueprints for these tests and sample questions are made publicly available by the California Department of Education. It is recommended that local education agencies review and (as necessary) improve their high school science programs so that:

1) All high school science courses that meet state or local graduation requirements, or UC/CSU entrance requirements, are based on the Science Content Standards;

2) Every laboratory science course is standards-based and ensures that students master both content-specific and investigation and experimentation standards;

3) Every science program ensures that students are prepared to be successful on the California Standards Tests;

4) All students take, at minimum, two years of laboratory science providing fundamental knowledge in at least two of the following content strands: biology/life sciences, chemistry, and physics. Laboratory courses in earth sciences are acceptable if they have as prerequisites (or provide basic knowledge in) biology, chemistry, or physics.

- ***Develop students' command of the academic language of science used in the content standards.***

Lessons explicitly teach scientific terms as they are presented in the content standards. New words (e.g., *photosynthesis*) are introduced to reflect students' expanding knowledge, and the definitions of common words (e.g., *table*) are expanded to incorporate specific meanings in science. Developing students' command of the academic language of science must be part of instruction at all grades (K-8) and in the four content strands (9-12). Scientific vocabulary is important in building conceptual understanding, and teachers need to provide explanations of new terms and idioms using words and examples that are clear and precise.

- ***Reflect a balanced, comprehensive approach that includes the teaching of investigation and experimentation skills along with direct instruction and reading.***

A balanced, comprehensive approach to science includes the teaching of investigation and experimentation skills along with direct instruction and reading. The investigation and experimentation standards are progressive and need to be taught in a manner integral to physical, life, and earth science content as students learn quantitative and qualitative observational skills. For example, the metric system is first introduced in the second grade, but students use and refine their skill in metric measurement through to high school. The methods and skills of scientific inquiry are learned in the context of the key concepts, principles, and theories set forth in the standards. Effective use of limited instructional time is always a major consideration in the design of lessons and courses. Laboratory space and materials, library access and resources are essential to support students' academic growth in science.

- ***Use multiple instructional strategies and provide students multiple opportunities to master the content standards.***

Multiple instructional strategies, including direct instruction, teacher modeling and demonstration, and investigation and experimentation, are useful in teaching science and need to be included in instructional materials. These strategies help teachers capture student interest, provide bridges across content areas, and contribute to understanding the nature of science and the methods of scientific inquiry. Standards for Investigation and Experimentation are included at each grade level and are different from the others in that they do not represent a specific content area. Investigation and experimentation cuts across all content areas, and these standards are intended to be taught in the context of the grade-level content and to comprise 20 to 25 percent of the science instructional time in grades K-8. Instruction is designed and sequenced to provide students opportunities to reinforce foundational skills and knowledge and to revisit concepts, principles, and theories previously taught. In this way, student progress is appropriately monitored.

- ***Assess students' knowledge and understanding on a continuing basis and make appropriate adjustments during the academic year.***

Effective assessment (on a continuing basis through the academic year) is a key ingredient of standards-based instruction. Teachers assess students' prerequisite knowledge, monitor student progress, and evaluate the degree of mastery of the content called for in the standards. Lessons include embedded unit assessments that provide formative and summative assessments of student progress. Teachers and administrators regularly collaborate to improve science progress by examining the results of California Standards Tests in science (both the test at grade 5 and the course-specific tests in grades 9-11).

- ***Engage all students in learning and prepare and motivate students for further instruction in science.***

Students who need special assistance to achieve grade-level expectations are identified early and receive support. Students who are unable to keep up with the expectations for learning science often lack basic skills in reading comprehension and mathematics. For these students, schools will want to use transitional materials that accelerate the students' reading and mathematics achievement to grade level. Advanced learners must not be held back, but rather be encouraged to study science content in greater depth.

- ***Utilize technology to teach and assess content knowledge, develop information resources, and enhance computer literacy.***

Across the nation, science in the laboratory setting involves specialized probes, instruments, materials, and computers. Scientists extend their ability to observe, analyze data, study the scientific literature, and communicate through the use of technology. High performance computing capabilities are used in science to make predictions based on fundamental principles and laws. Technology-based models are used to design and guide experiments, making it possible to eliminate some experiments and to suggest other experiments that previously might not have been considered. Students have the opportunity to use technology and model the way modern science is done. Teaching science using technology is important for preparing students simultaneously to be scientifically and technologically literate. Assembly Bill 1023 (Chapter 404, Statutes of 1997) requires that newly credentialed teacher demonstrate basic competence in the use of computers in the classroom.

- ***Have adequate instructional resources as well as library-media and administrative support.***

Standards-based teaching and learning in science demands adequate instructional resources. LEAs and individual school sites need to include science resources as an integral part of the budget. Library-media staff must have science as a priority for resource acquisition and development. Administrators must ensure that funds set aside for the science resources are spent efficiently (e.g., through clear processes and procedures for purchasing and maintenance) and support students' mastery of the content standards. This requires planning, coordination, and dedication of space for the science resources.

- ***Utilize standards-based connections with other core subjects to reinforce science teaching and learning.***

Science instruction provides multiple opportunities to make connections with other content areas. Reading, writing, mathematics, and oral skills are needed to learn and do science. In self-contained classrooms, teachers incorporate science content in reading, writing, and mathematics in keeping with the *Reading-Language Arts* and *Mathematics Frameworks*. In departmentalized settings (middle and high school levels), science teachers need to include essay assignments and require that students' writing reflect the correct application of English-language conventions, including spelling and grammar.

Organization of the Framework

This framework is primarily organized around the *Science Content Standards for California Public Schools* (California Department of Education 2000). The framework:

- Discusses the nature of science and technology, and the methods by which they are advanced (Chapter 2).
- Describes the curriculum content and instructional practices needed for mastery of the standards. (Chapter 3).
- Guides the development of appropriate assessment tools (Chapter 4).
- Suggests specific strategies to promote access to the curriculum for students with special needs (Chapter 5).
- Describes the system of teacher professional development that needs to be in place for effective implementation of the standards (Chapter 6).
- Specifies the requirements for instructional resources, including investigative activities (Chapter 7).

The California *Science Content Standards* are embedded in Chapter 3, and are grade-level specific from Kindergarten through Grade 8. The standards for Grades 9-12 are organized into the content areas of Physics, Chemistry, Biology, and Earth Sciences.